

Environmental trade-offs of pig production systems under varied operational efficiencies

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Supplementary material (11 pages)

List of abbreviations:

AVG: average herd performance

T25: top 25% herd performance

T10: top 10% herd performance

GWP: global warming potential

AP: acidification potential

EP: eutrophication potential

Table S1. Life cycle inventory for slaughterhouse process.

| | Unit | T10 | T25 | AVG |
|---------------------|------|-------|-------|-------|
| <i>Inputs</i> | | | | |
| Liveweight | kg | 1000 | 1000 | 1000 |
| Electricity | kWh | 248.9 | 248.4 | 251.6 |
| Diesel | kg | 7.4 | 7.4 | 7.5 |
| Transport | km | 50 | 50 | 50 |
| <i>Outputs</i> | | | | |
| Carcass weight | kg | 761.7 | 763.4 | 762.4 |
| <i>Losses</i> | | | | |
| CO | g | 2.8 | 2.8 | 2.8 |
| CO ₂ | kg | 42.1 | 42.1 | 42.6 |
| NO _x | g | 27.9 | 27.8 | 28.2 |
| N ₂ O | g | 0.7 | 0.7 | 0.8 |
| CH ₄ | g | 0.8 | 0.8 | 0.8 |
| BOD ₅ | g | 879.5 | 877.8 | 888.9 |
| COD | kg | 22.9 | 22.8 | 23.1 |
| N | kg | 3.0 | 3.0 | 3.0 |
| P | g | 263.7 | 263.3 | 266.6 |
| Biodegradable waste | kg | 3.7 | 3.7 | 3.8 |

Table S2. Uncertainty parameters adopted in Monte Carlo analysis.

| Emission | Uncertainty | Distribution | Reference |
|--|-------------------------|--------------|-----------------------|
| CH ₄ (enteric fermentation) | ± 17% | Triangular | Duffy et al. (2017) |
| CH ₄ (manure management) | ± 19% | Triangular | |
| N ₂ O (all emissions) | 2 (SD ²) | Lognormal | IPCC (2006) |
| NH ₃ (all emissions) | ± 21% | Triangular | Amon et al. (2016) |
| NO _x (all emissions) | 2 (SD ²) | Lognormal | |
| NO ₃ | 1.58 (SD ²) | Lognormal | Pedigree matrix |
| PO ₄ | 1.58 (SD ²) | Lognormal | (Muller et al., 2016) |

Table S3. Environmental impacts for the average (AVG) farm based on the baseline analysis.

| Item | GWP (g CO ₂ -eq) | AP (g SO ₂ -eq) | EP (g PO ₄ -eq) |
|--|-----------------------------|----------------------------|----------------------------|
| <i>Feed production and transportation</i> | | | |
| Dry sow | 237 | 2.3 | 2 |
| Lactating sow | 54.6 | 0.5 | 0.4 |
| Gilt | 42.4 | 0.4 | 0.4 |
| Weaner | 388 | 3.4 | 2.9 |
| Finisher | 1310 | 12.7 | 10.5 |
| <i>Transport of feed from mill to farm</i> | | | |
| By truck | 29.5 | 0.1 | < 0.1 |
| <i>Energy use</i> | | | |
| Electricity | 130 | 0.5 | 0.4 |
| Heat (oil) | 51 | 0.1 | < 0.1 |
| <i>Farm emissions</i> | | | |
| Methane | | | |
| Enteric fermentation | 178.5 | - | - |
| Manure management | 813.1 | - | - |
| Nitrous oxide | 118 | - | < 0.1 |
| Ammonia | - | 11.3 | 2.5 |
| Nitrogen oxides | - | 0.4 | < 0.1 |
| Manure utilisation | | | |
| Transport | 36 | 0.3 | < 0.1 |
| Spreading | 15.9 | < 0.1 | < 0.1 |
| Nitrous oxide | 262 | - | |
| Ammonia | - | 12.2 | 2.7 |
| Nitrogen oxides | - | < 0.1 | < 0.1 |
| Nitrate | - | - | 5.9 |
| Phosphate | - | - | 0.3 |
| <i>Avoided fertiliser production</i> | | | |
| from manure nitrogen | -334 | - | - |
| from manure phosphorus | -39.4 | - | - |
| from manure potassium | -27.4 | - | - |
| <i>Avoided fertiliser application</i> | | | |
| Spreading | -1.6 | - < 0.1 | - < 0.1 |
| Nitrous oxide | -62.8 | - | - < 0.1 |
| Ammonia | - | -1.7 | -0.4 |
| Nitrogen oxides | - | -0.2 | - < 0.1 |
| <i>Slaughterhouse</i> | | | |
| Electricity | 239 | 1 | 0.6 |
| Diesel | 5.7 | < 0.1 | < 0.1 |
| Transport | 3.9 | < 0.1 | < 0.1 |
| Landfill | 2.5 | < 0.1 | < 0.1 |
| Emissions (aggregated) | 50 | 0.1 | 3.4 |

Table S4. Environmental impacts for the T25 farm based on the baseline analysis.

| Item | GWP (g CO ₂ -eq) | AP (g SO ₂ -eq) | EP (g PO ₄ -eq) |
|--|-----------------------------|----------------------------|----------------------------|
| <i>Feed production and transportation</i> | | | |
| Dry sow | 227 | 2.2 | 1.9 |
| Lactating sow | 51.1 | 0.5 | 0.4 |
| Gilt | 41 | 0.4 | 0.3 |
| Weaner | 385 | 3.5 | 2.9 |
| Finisher | 1160 | 11.2 | 9.3 |
| <i>Transport of feed from mill to farm</i> | | | |
| By truck | 27 | 0.1 | < 0.1 |
| <i>Energy use</i> | | | |
| Electricity | 128 | 0.5 | 0.3 |
| Heat (oil) | 50.3 | 0.1 | < 0.1 |
| <i>Farm emissions</i> | | | |
| Methane | | | |
| Enteric fermentation | 171.6 | - | - |
| Manure management | 780.6 | - | - |
| Nitrous oxide | 100.7 | - | < 0.1 |
| Ammonia | - | 9.7 | 2.2 |
| Nitrogen oxides | - | 0.3 | < 0.1 |
| Manure utilisation | | | |
| Transport | 30.7 | 0.2 | < 0.1 |
| Spreading | 13.6 | < 0.1 | < 0.1 |
| Nitrous oxide | 223.8 | - | 0.1 |
| Ammonia | - | 10.4 | 2.2 |
| Nitrogen oxides | - | < 0.1 | < 0.1 |
| Nitrate | - | - | 5.1 |
| Phosphate | - | - | 0.2 |
| <i>Avoided fertiliser production</i> | | | |
| from manure nitrogen | -285 | - | - |
| from manure phosphorus | -29 | - | - |
| from manure potassium | -24.9 | - | - |
| <i>Avoided fertiliser application</i> | | | |
| Spreading | -1.4 | - < 0.1 | - < 0.1 |
| Nitrous oxide | -53.6 | - | - < 0.1 |
| Ammonia | - | -1.5 | -0.3 |
| Nitrogen oxides | - | - | - < 0.1 |
| <i>Slaughterhouse</i> | | | |
| Electricity | 236 | 1 | 0.6 |
| Diesel | 5.6 | < 0.1 | < 0.1 |
| Transport | 3.8 | < 0.1 | < 0.1 |
| Landfill | 2.5 | < 0.1 | < 0.1 |
| Emissions (aggregated) | 60 | 0.1 | 3.4 |

Table S5. Environmental impacts for the T10 farm based on the baseline analysis.

| Item | GWP (g CO ₂ -eq) | AP (g SO ₂ -eq) | EP (g PO ₄ -eq) |
|--|-----------------------------|----------------------------|----------------------------|
| <i>Feed production and transportation</i> | | | |
| Dry sow | 216 | 2.1 | 1.8 |
| Lactating sow | 52.5 | 0.5 | 0.4 |
| Gilt | 39 | 0.4 | 0.3 |
| Weaner | 340 | 3.1 | 2.6 |
| Finisher | 1200 | 11.6 | 9.6 |
| <i>Transport of feed from mill to farm</i> | | | |
| By truck | 26.8 | 0.1 | < 0.1 |
| <i>Energy use</i> | | | |
| Electricity | 129 | 0.5 | 0.3 |
| Heat (oil) | 50.6 | 0.1 | < 0.1 |
| <i>Farm emissions</i> | | | |
| Methane | | | |
| Enteric fermentation | 171.3 | - | - |
| Manure management | 789.6 | - | - |
| Nitrous oxide | 97.4 | - | < 0.1 |
| Ammonia | - | 9.4 | 2 |
| Nitrogen oxides | - | 0.3 | < 0.1 |
| Manure utilisation | | | |
| Transport | 29.7 | 0.2 | < 0.1 |
| Spreading | 13.2 | < 0.1 | < 0.1 |
| Nitrous oxide | 215.8 | - | 0.1 |
| Ammonia | - | 10.1 | 2.2 |
| Nitrogen oxides | - | < 0.1 | < 0.1 |
| Nitrate | - | - | 4.9 |
| Phosphate | - | - | 0.2 |
| <i>Avoided fertiliser production</i> | | | |
| from manure nitrogen | -276 | - | - |
| from manure phosphorus | -27.7 | - | - |
| from manure potassium | -24.5 | - | - |
| <i>Avoided fertiliser application</i> | | | |
| Spreading | -1.3 | - < 0.1 | - < 0.1 |
| Nitrous oxide | -51.8 | - | - < 0.1 |
| Ammonia | - | -1.4 | -0.3 |
| Nitrogen oxides | - | -0.1 | - < 0.1 |
| <i>Slaughterhouse</i> | | | |
| Electricity | 237 | 1 | 0.6 |
| Diesel | 5.6 | < 0.1 | < 0.1 |
| Transport | 3.9 | < 0.1 | < 0.1 |
| Landfill | 2.5 | < 0.1 | < 0.1 |
| Emissions (aggregated) | 60 | < 0.1 | 3.4 |

Table S6. Percentage differences in LCA outputs of scenario and sensitivity analyses relative to the baseline results.

| | AVG | | | T25 | | | T10 | | |
|------------------------------------|-------|------|------|-------|------|------|-------|------|------|
| | GWP | AP | EP | GWP | AP | EP | GWP | AP | EP |
| On-farm feed mill | -11.1 | 13.5 | 6.5 | -10.9 | 13.9 | 6.6 | -10.9 | 13.1 | 5.9 |
| Domestic wheat and barley | -1.1 | 0.2 | -0.6 | -0.9 | 0.0 | -0.7 | -0.9 | 0.3 | -0.7 |
| Mass allocation | 6.3 | 5.3 | 6.5 | 6.1 | 5.1 | 6.6 | 6.1 | 5.5 | 6.6 |
| Inclusion of land use change | 80.9 | - | - | 79.7 | - | - | 77.9 | - | - |
| High on-farm energy usage | 3.1 | 0.9 | 0.6 | 3.3 | 1.0 | 0.7 | 3.3 | 1.0 | 0.7 |
| Low on-farm energy usage | -2.0 | -0.5 | -0.3 | -1.8 | -0.5 | -0.7 | -2.1 | -0.5 | -0.7 |
| Exclusion of fertiliser offsetting | 13.1 | 4.3 | 1.6 | 11.8 | 4.1 | 1.4 | 11.5 | 4.2 | 1.4 |

Table S7. Environmental impacts for the average (AVG) farm when feeds are sourced from the on-farm mill.

| Item | GWP (g CO ₂ -eq) | AP (g SO ₂ -eq) | EP (g PO ₄ -eq) |
|--|-----------------------------|----------------------------|----------------------------|
| <i>Feed production and transportation</i> | | | |
| Dry sow | 180 | 1.6 | 1.4 |
| Lactating sow | 44.8 | 0.4 | 0.3 |
| Gilt | 32.2 | 0.3 | 0.3 |
| Weaner | 341 | 2.8 | 2.4 |
| Finisher | 1090 | 9.7 | 8.3 |
| <i>Transport of feed from mill to farm</i> | | | |
| By truck | - | - | - |
| <i>Energy use</i> | | | |
| Electricity | 130 | 0.5 | 0.4 |
| Heat (oil) | 51 | 0.1 | < 0.1 |
| <i>Farm emissions</i> | | | |
| Methane | | | |
| Enteric fermentation | 178.5 | - | - |
| Manure management | 813.1 | - | - |
| Nitrous oxide | 174.1 | - | 0.1 |
| Ammonia | - | 16.9 | 3.7 |
| Nitrogen oxides | - | 0.6 | 0.1 |
| Manure utilisation | | | |
| Transport | 53.1 | 0.4 | < 0.1 |
| Spreading | 23.5 | 0.1 | < 0.1 |
| Nitrous oxide | 386 | - | 0.3 |
| Ammonia | - | 17.9 | 4 |
| Nitrogen oxides | - | < 0.1 | < 0.1 |
| Nitrate | - | - | 8.8 |
| Phosphate | - | - | 0.5 |
| <i>Avoided fertiliser production</i> | | | |
| from manure nitrogen | -493 | - | - |
| from manure phosphorus | -68.2 | - | - |
| from manure potassium | -37.4 | - | - |
| <i>Avoided fertiliser application</i> | | | |
| Farm traction | -2.4 | - < 0.1 | - < 0.1 |
| Nitrous oxide | -92.8 | - | - < 0.1 |
| Ammonia | - | -2.5 | -0.5 |
| Nitrogen oxides | - | -0.2 | - < 0.1 |
| <i>Slaughterhouse</i> | | | |
| Electricity | 239 | 1 | 0.6 |
| Diesel | 5.7 | < 0.1 | - < 0.1 |
| Transport | 3.9 | < 0.1 | - < 0.1 |
| Landfill | 2.5 | < 0.1 | - < 0.1 |
| Emissions (aggregated) | 60 | < 0.1 | 3.4 |

Table S8. Environmental impacts for the T25 farm when feeds are sourced from the on-farm mill.

| Item | GWP (g CO ₂ -eq) | AP (g SO ₂ -eq) | EP (g PO ₄ -eq) |
|--|-----------------------------|----------------------------|----------------------------|
| <i>Feed production and transportation</i> | | | |
| Dry sow | 173 | 1.6 | 1.4 |
| Lactating sow | 41.9 | 0.4 | 0.3 |
| Gilt | 31.1 | 0.3 | 0.2 |
| Weaner | 339 | 2.8 | 2.4 |
| Finisher | 967 | 8.6 | 7.4 |
| <i>Transport of feed from mill to farm</i> | | | |
| By truck | - | - | - |
| <i>Energy use</i> | | | |
| Electricity | 128 | 0.5 | 0.3 |
| Heat (oil) | 50.3 | 0.1 | < 0.1 |
| <i>Farm emissions</i> | | | |
| Methane | | | |
| Enteric fermentation | 171.6 | - | - |
| Manure management | 780.6 | - | - |
| Nitrous oxide | 152.2 | - | < 0.1 |
| Ammonia | - | 14.7 | 3.2 |
| Nitrogen oxides | - | 0.6 | < 0.1 |
| Manure utilisation | | | |
| Transport | 46.5 | 0.3 | < 0.1 |
| Spreading | 20.6 | 0.1 | < 0.1 |
| Nitrous oxide | 338 | - | 0.3 |
| Ammonia | - | 15.7 | 3.5 |
| Nitrogen oxides | - | < 0.1 | < 0.1 |
| Nitrate | - | - | 7.7 |
| Phosphate | - | - | 0.4 |
| <i>Avoided fertiliser production</i> | | | |
| from manure nitrogen | -431 | - | - |
| from manure phosphorus | -55.6 | - | - |
| from manure potassium | -34.1 | - | - |
| <i>Avoided fertiliser application</i> | | | |
| Farm traction | -2.1 | - < 0.1 | - < 0.1 |
| Nitrous oxide | -81.1 | - | - < 0.1 |
| Ammonia | - | -2.2 | -0.5 |
| Nitrogen oxides | - | -0.2 | - < 0.1 |
| <i>Slaughterhouse</i> | | | |
| Electricity | 236 | 1 | 0.6 |
| Diesel | 5.6 | < 0.1 | < 0.1 |
| Transport | 3.8 | < 0.1 | < 0.1 |
| Landfill | 2.5 | < 0.1 | < 0.1 |
| Emissions (aggregated) | 50 | < 0.1 | 3.3 |

Table S9. Environmental impacts for the T10 farm when feeds are sourced from the on-farm mill.

| Item | GWP (g CO ₂ -eq) | AP (g SO ₂ -eq) | EP (g PO ₄ -eq) |
|--|-----------------------------|----------------------------|----------------------------|
| <i>Feed production and transportation</i> | | | |
| Dry sow | 164 | 1.5 | 1.3 |
| Lactating sow | 43.1 | 0.4 | 0.3 |
| Gilt | 29.6 | 0.3 | 0.2 |
| Weaner | 299 | 2.4 | 2.1 |
| Finisher | 1000 | 8.9 | 7.7 |
| <i>Transport of feed from mill to farm</i> | | | |
| By truck | - | - | - |
| <i>Energy use</i> | | | |
| Electricity | 129 | 0.5 | 0.3 |
| Heat (oil) | 50.6 | 0.1 | < 0.1 |
| <i>Farm emissions</i> | | | |
| Methane | | | |
| Enteric fermentation | 171.3 | - | - |
| Manure management | 789.6 | - | - |
| Nitrous oxide | 146.4 | - | < 0.1 |
| Ammonia | - | 14.2 | 3.1 |
| Nitrogen oxides | - | 0.5 | < 0.1 |
| Manure utilisation | | | |
| Transport | 44.8 | 0.3 | < 0.1 |
| Spreading | 19.8 | < 0.1 | < 0.1 |
| Nitrous oxide | 326 | - | 0.3 |
| Ammonia | - | 15.2 | 3.3 |
| Nitrogen oxides | - | < 0.1 | < 0.1 |
| Nitrate | - | - | 7.4 |
| Phosphate | - | - | 0.4 |
| <i>Avoided fertiliser production</i> | | | |
| from manure nitrogen | -416 | - | - |
| from manure phosphorus | -53.9 | - | - |
| from manure potassium | -33.6 | - | - |
| <i>Avoided fertiliser application</i> | | | |
| Farm traction | -2 | - < 0.1 | - < 0.1 |
| Nitrous oxide | -78.1 | - | - < 0.1 |
| Ammonia | - | -2.1 | -0.5 |
| Nitrogen oxides | - | -0.2 | - < 0.1 |
| <i>Slaughterhouse</i> | | | |
| Electricity | 237 | 1 | 0.6 |
| Diesel | 5.6 | < 0.1 | < 0.1 |
| Transport | 3.9 | < 0.1 | < 0.1 |
| Landfill | 2.5 | < 0.1 | < 0.1 |
| Emissions (aggregated) | 50 | < 0.1 | 3.4 |

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